RDECOM

Measurement of In-Bore Side Loads and Comparison to First Maximum Yaw

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Outline

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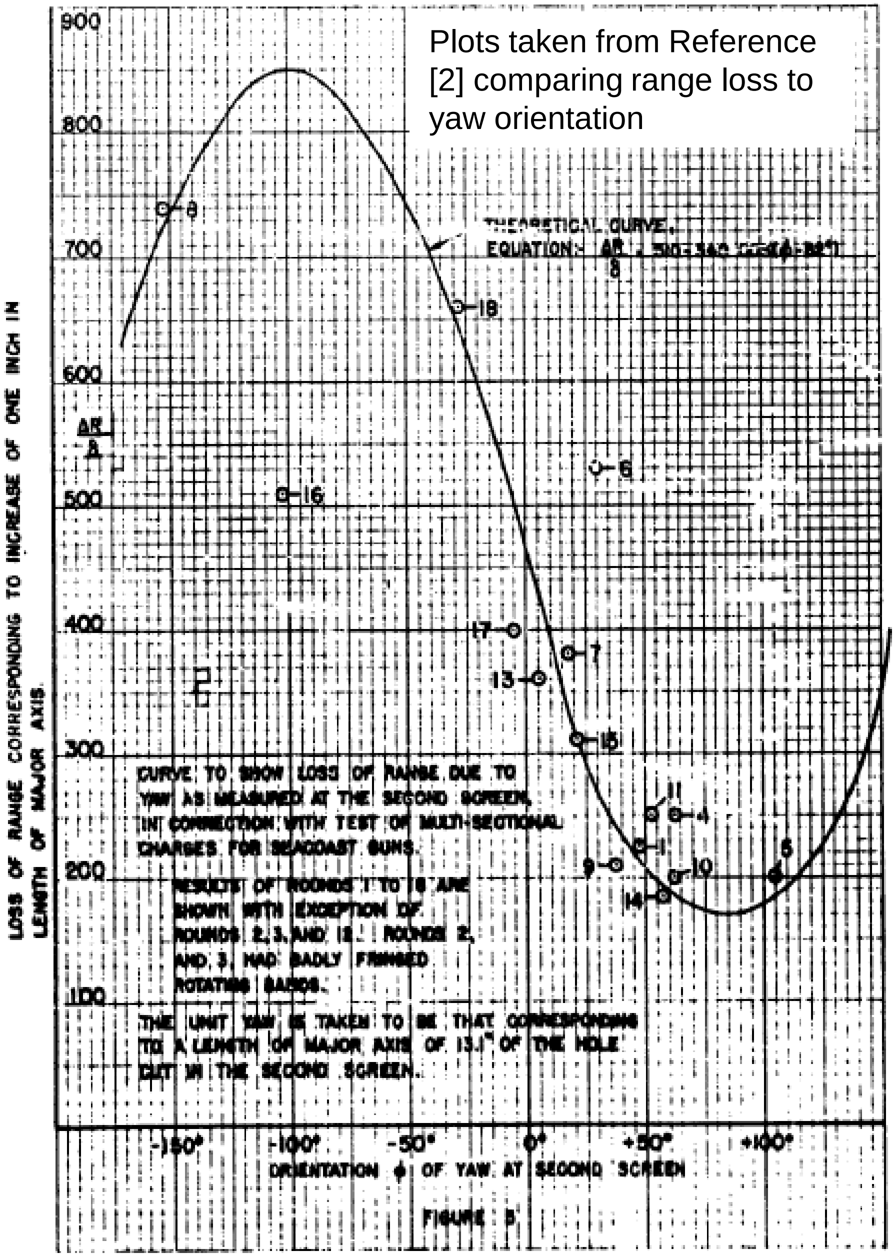
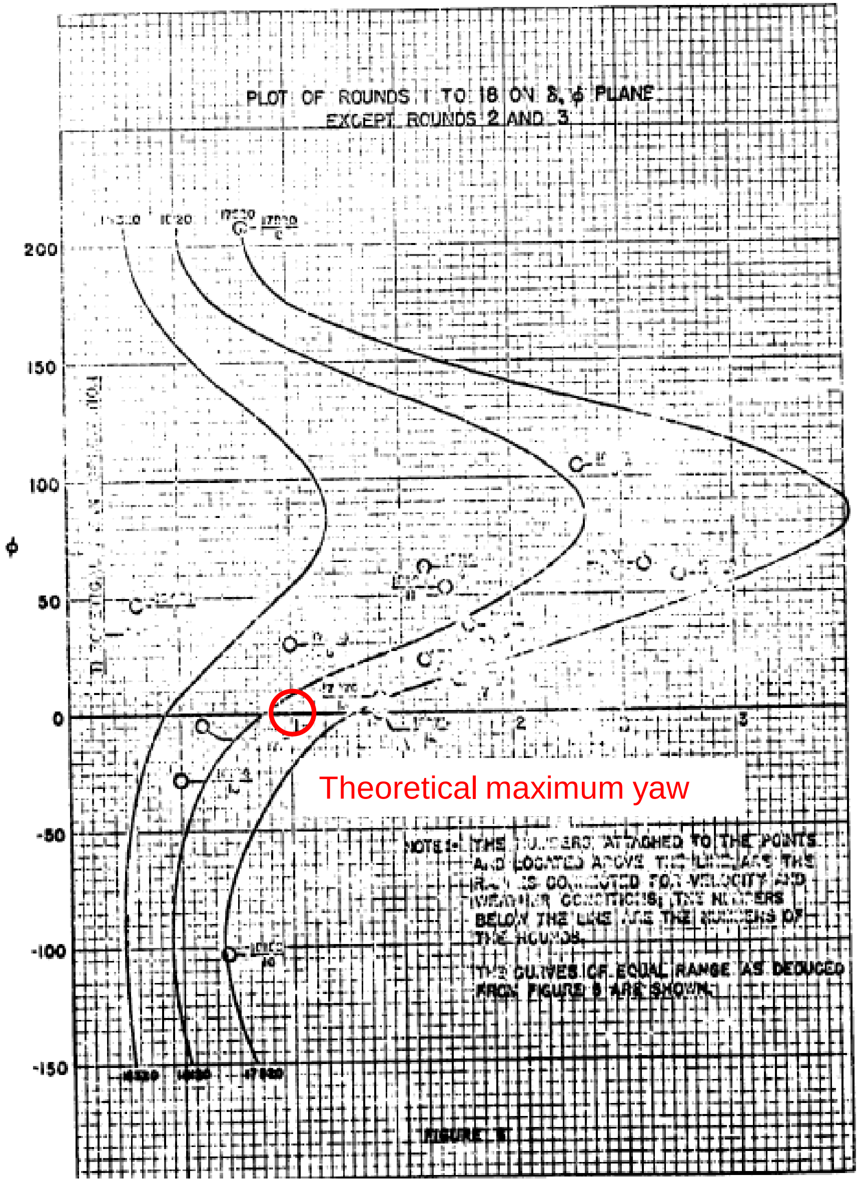
Background

- First maximum yaw is a good indicator of range loss in a given projectile type
  - Not all projectile designs yaw damp at the same rate
  - Projectiles of the same design should damp at the same rate and exhibit the same drag except for variations in
    - Mass distribution (design tolerances)
    - Launch disturbance
    - Down-bore motion (in-bore yaw)
    - Geometry variations (design tolerances)
    - Meteorological conditions
- The effect of bore clearance (at the muzzle) on range loss was documented in [1]
  - The more bore clearance, in general, the shorter the range to impact
- Kent, et al., documented an attempt at correlating bore clearance to range loss [2]

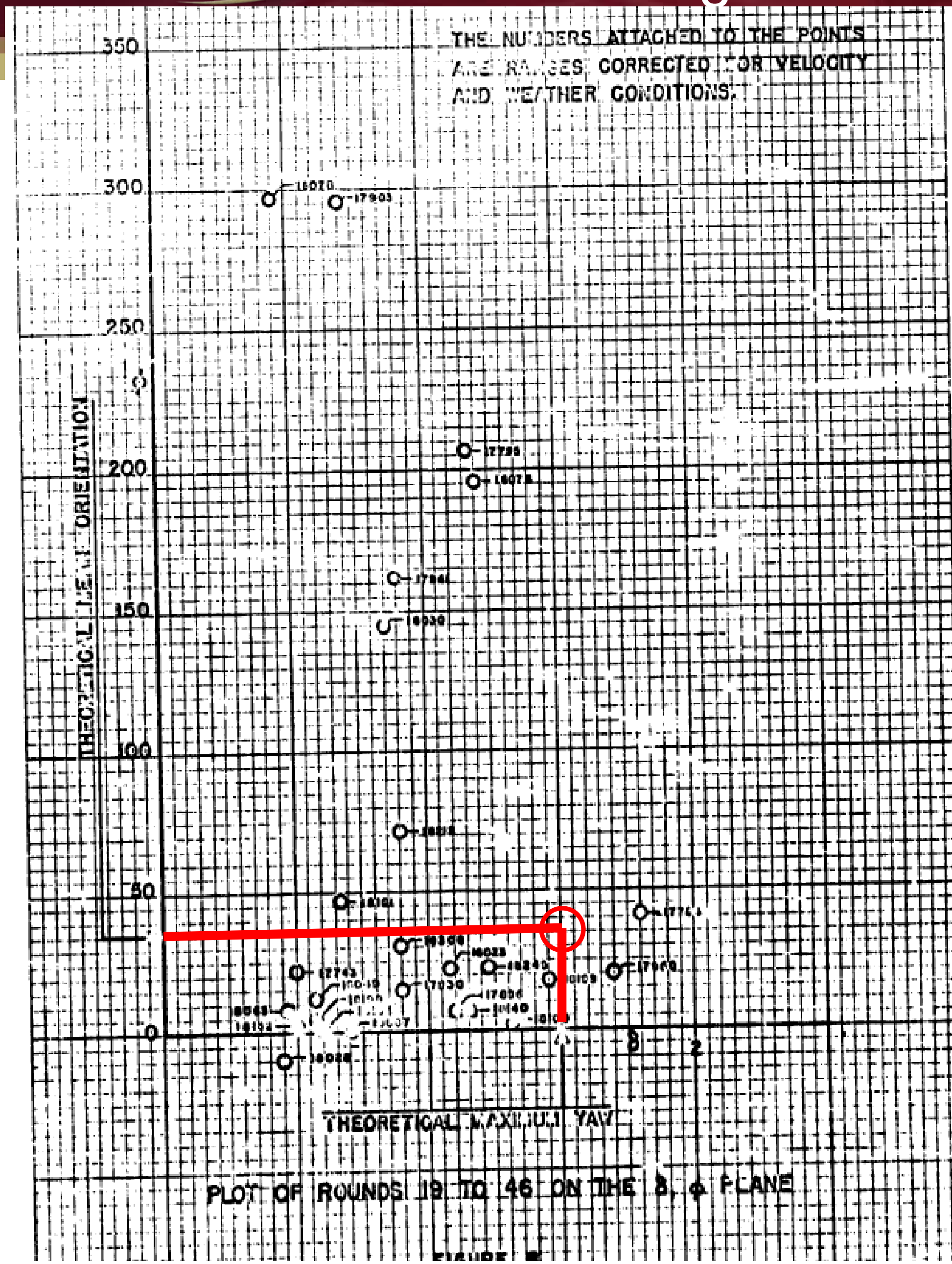
[1] Breger, M. P., Morrison, C. C. (Transl.). “Position and Form of Bands for Projectiles”, *Notes on the Construction of Ordnance*, No. 27., Washington D. C., 10 June 1884.
[2] Kent, R. H., Hitchcock, H. P., Comparison of Predicted and Observed Yaw in Front of the Muzzle of a 12” Gun, Report No. 990 AD-116-140, USA BRL, Aberdeen Proving Ground, MD, July 1956.

Background (Cont'd)





Background (Cont'd)



$$FMY = \left(\frac{2I_{\mathrm{T}}}{I_{\mathrm{P}}} - 1 \right) \frac{\delta_{tm}}{\sqrt{1 - \frac{1}{S_g}}} \qquad (1)$$

$$\delta_{tm} \approx \frac{d_{bore} - d}{l_{bb}} \qquad (2)$$

Plots taken from Reference [2] comparing first maximum yaw to in-bore clearance

Goal of the Effort

- Determine relationship between in-bore clearance and first maximum yaw

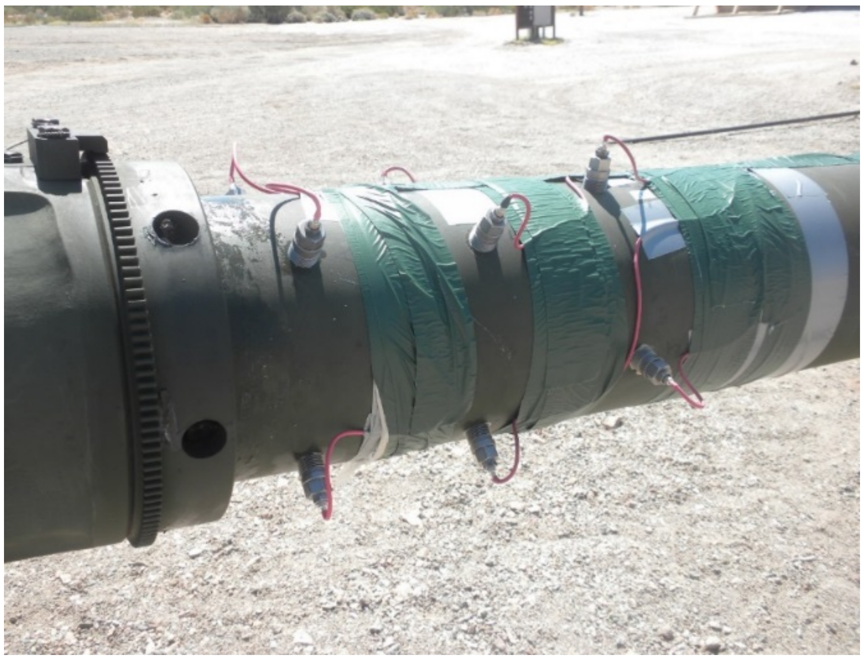
- Determine the maximum bore clearance allowable before range loss becomes unacceptable

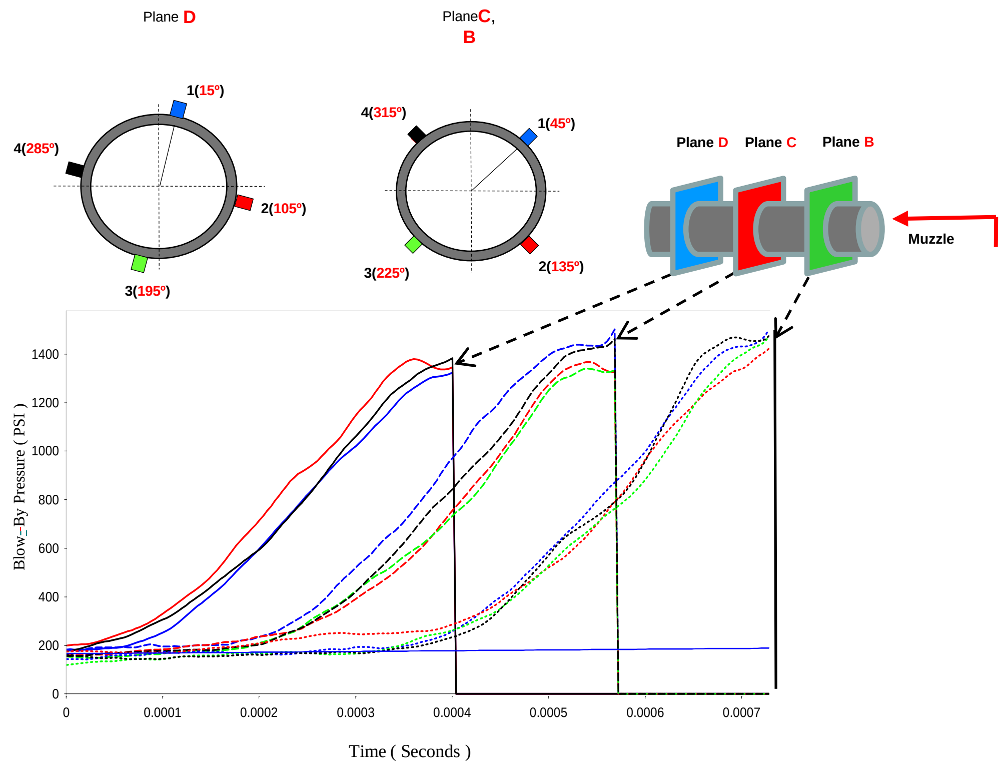
Approach

- Through use of pressure transducers determine the force and moment acting on the projectile as it leaves the muzzle of the weapon
- In theory this should allow one to predict the magnitude and location of FMY (as well as the behavior through the rest of the flight)
- In practice it is not quite that simple
  - Weapon is moving
  - Projectile is moving
  - Finite number of pressure transducers
    - Where to put them?
    - How many is enough?
    - What do you assume for the data between transducers?
      - Axially
      - Radially
  - Gases influence outside of muzzle brake
- Knowing these limitations can we hope for a correlation?

Approach (Cont'd)

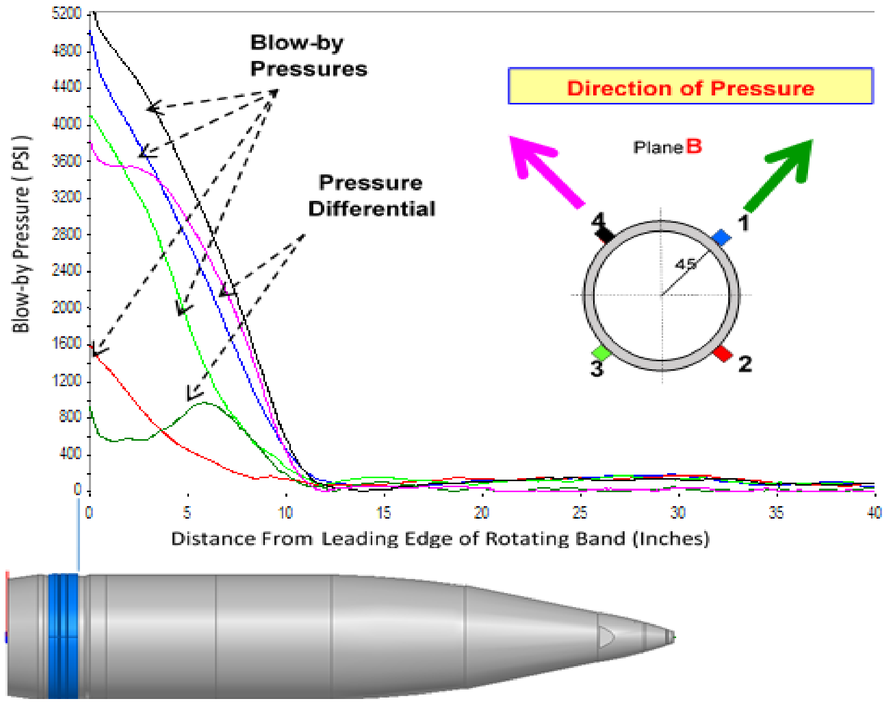
- Gun tube structural reasons forced locations inside the tube
  - 12 transducers total
  - 3 sets of 4 (10, 15 and 20 inches from the muzzle of the weapon)
  - One set in the grooves





Approach (Cont'd)

- As the projectile passes each set of transducers we obtain pressure data at that location over the time of passage
- Knowing the projectile velocity we obtain a curve looking "backwards" along the projectile length at four circumferential locations
- Assuming each of these pressures acts uniformly over a 90 degree segment we can calculate a "net"
  - Pressure force
  - Direction
  - Center of pressure
- We can now use the CG location to compute a net moment and it's direction of application

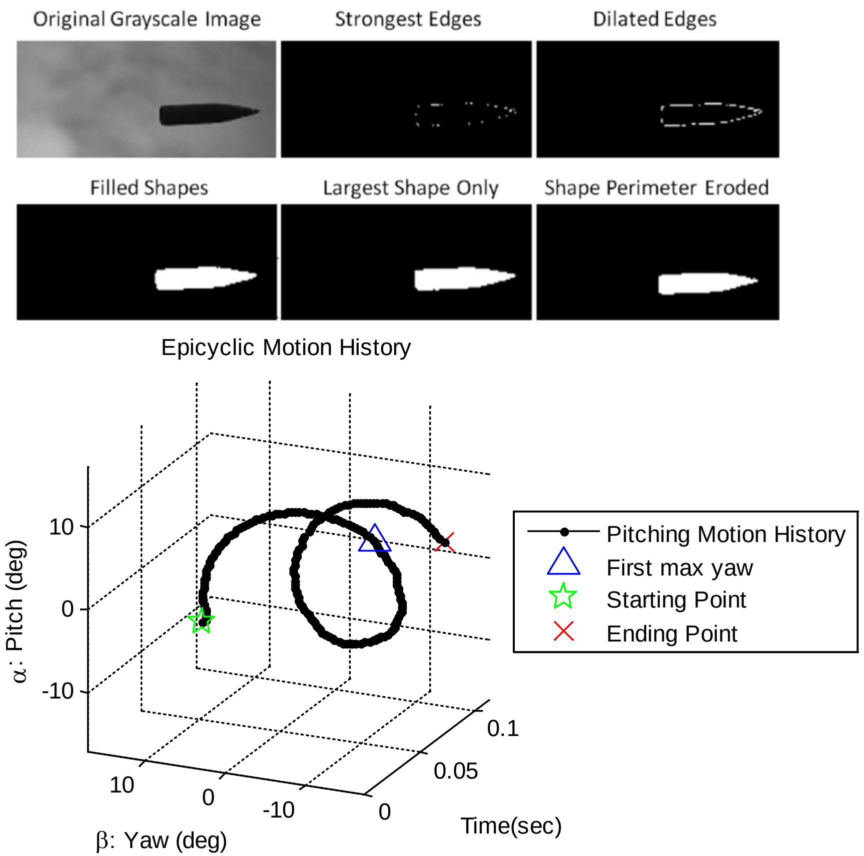


Approach (Cont'd)

- Thus for each firing we know the applied moment
- Unfortunately this moment is applied in the tube so it's not exactly the moment that is acting on the projectile when it is free of the weapon constraints
- So if we can measure where the first maximum yaw occurs we would hope to be able to see
  - If the magnitude correlates
  - If the orientation correlates
- If this can be determined we can ask ourselves
  - Does the pressure "bubble" rotate with the rifling?

Experimental Set Up

- The pressure transducer set up was depicted earlier
- The camera coverage to determine FMY consisted of two orthogonal flight follower camera systems as depicted below



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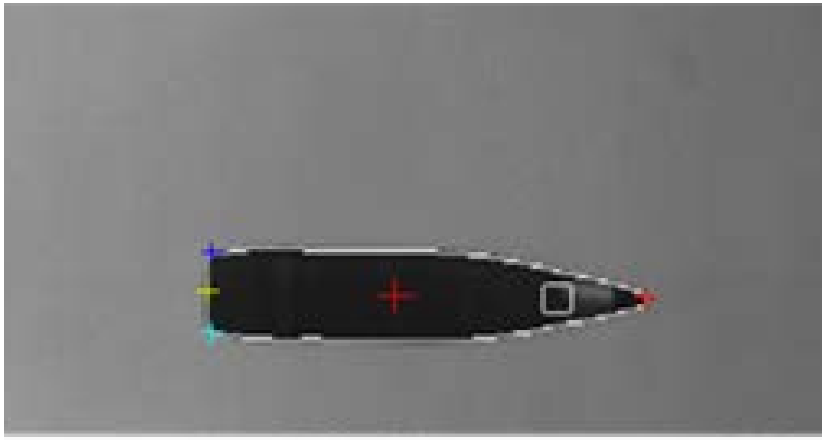
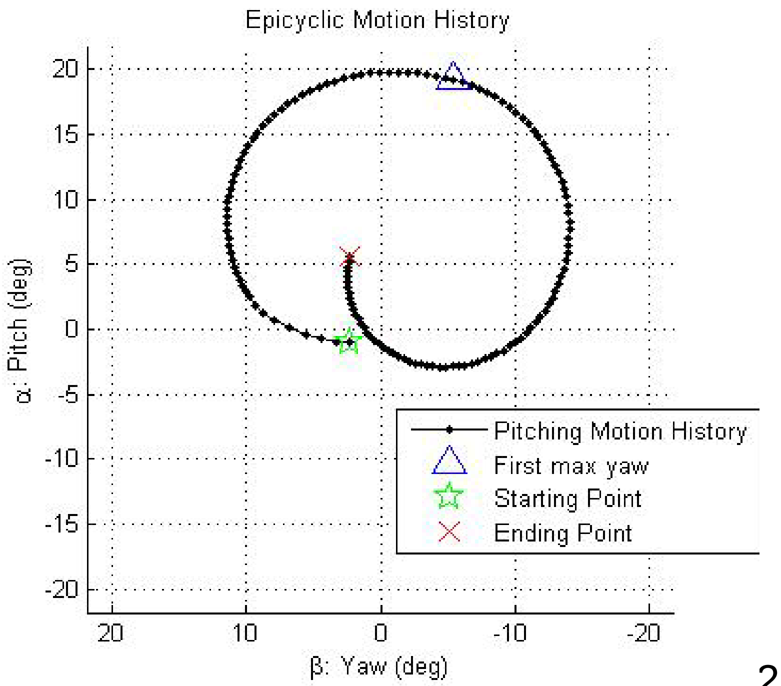
Experimental Results

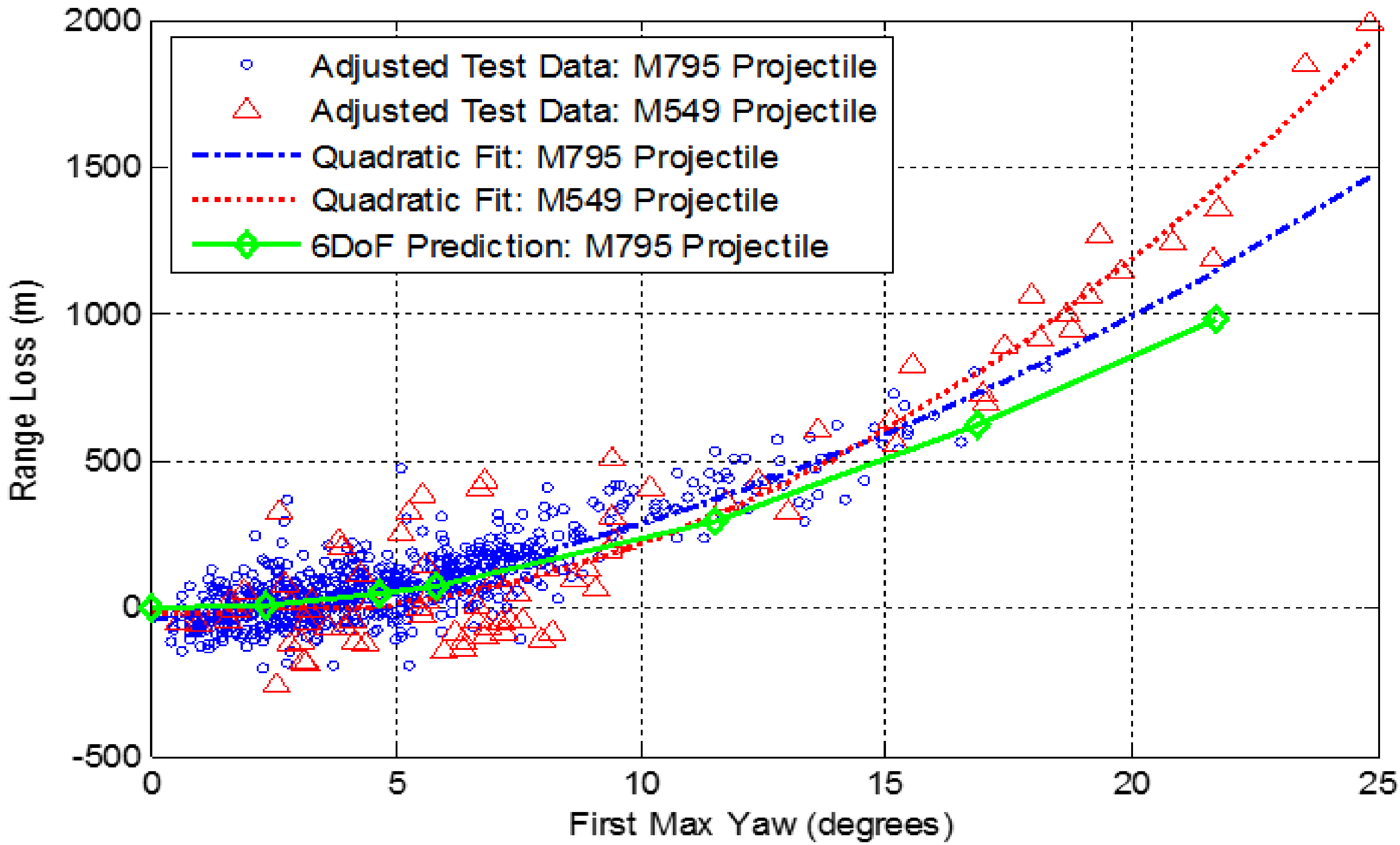
- The Automated Launch Video Analysis (ALVA) system was used to capture the projectile motion and validated against several instrumented projectiles
  - The system will be described in the paper by R. Decker
- The system was able to capture the projectile motion and determine the location and magnitude of FMY within 0.1 degrees



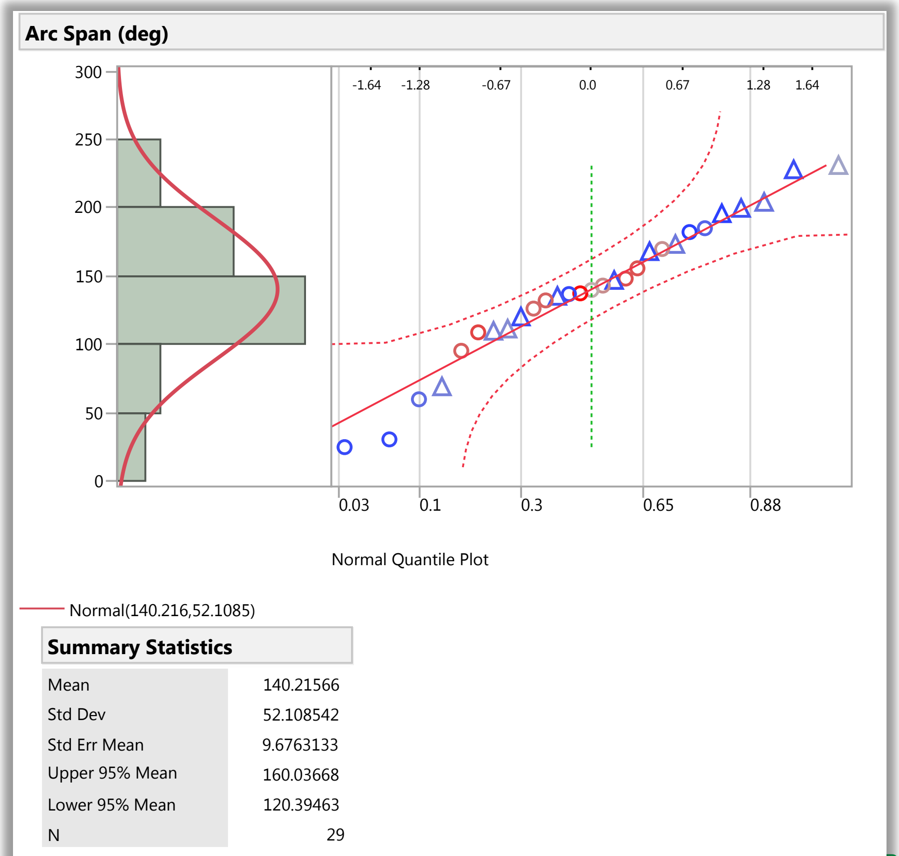


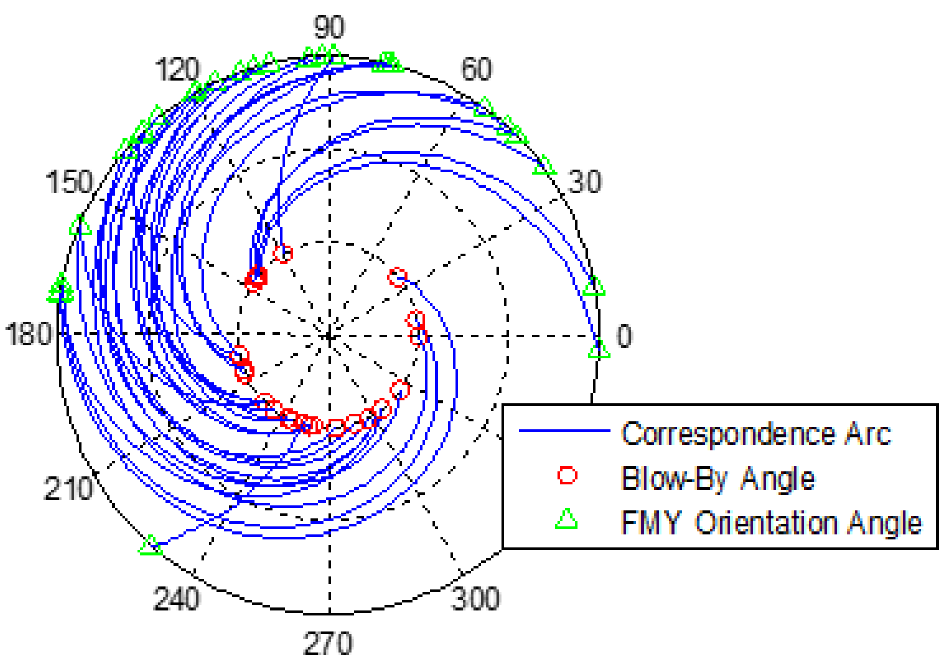
Experimental Results (Cont'd)

- The relationship between FMY and range loss was successfully observed and empirically modeled
  - This is nice and reinforced what was observed in the past



- The relationship between the magnitude and orientation of FMY and the magnitude and orientation of the net pressure force and its corresponding moment was also observed but it is noisy
  - There was a correction made for the rotation of the projectile from when the pressure data was taken





Analysis of the Results (Cont'd)

- The statistical analysis of the data showed
  - 59% of the variation in overturning moment direction in the tube was explained by 'blow-by angle'
  - 41% of the data did not and is attributed to the other suspected but unquantified sources of variation
    - Weapon is moving during and after measurement
    - Projectile is moving during and after measurement
    - Finite number of pressure transducers
      - Where they were
      - How many we had
      - How we integrated between them
    - Gases influence outside of muzzle brake
    - Others?
  - Different projectiles behaved differently
    - M549: 76% of variation explained by overturning torque
    - M795 : 24% of variation explained by overturning torque
    - Geometry related?

Summary and Conclusions

- First Maximum Yaw (Still) is directly related to range loss
- In-Bore moments caused by blow-by affect FMY
  - Differently for different projectiles
  - Other factors are at work
- Accurate measurements of FMY can be obtained by video means (more in the Decker paper)
- Although no future work is currently planned by ARDEC to delve more deeply into this topic there are still a great many questions that need to be answered

Thank You

Questions?